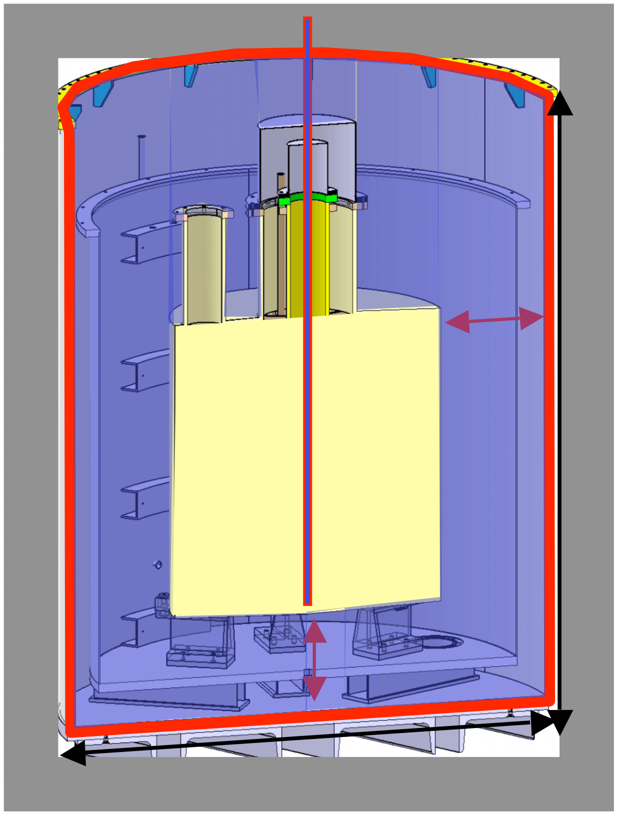
Double Chooz Mock-up : Towards Thermal Measurement and Non Proliferation Initiatives



TH. LASSERRE

CEA/Saclay/DAPNIA/SPP & APC

Outline

- ***From Thermal power measurement to Non proliferation with neutrinos***
  - *Isotropic anti-νe flux from uranium & plutonium fission fragments*
  - *Detection tag : anti-ν_e + p → e^+ + n, <E>~ 4 MeV, Threshold ~1.8 MeV*

- ***Double Chooz mock-up***
  - *Mechanics*
  - *Scintllator & Filling System, Safety*
  - *Towards an instrumented mock-up …*

- ***Instrumented mockup***
  - *GEANT4 detector simulation*
  - *PMT's & Light output*
  - *Spatial & time response to e+, e-, γ, & neutron sources*

- ***Expected performance at reactor***
  - *Experimental configuration*
  - *Detector response to reactor anti-neutrinos: e+ and neutron*
  - *Burn-up detection: before and after detector response*

- ***Conclusions & Outlook***

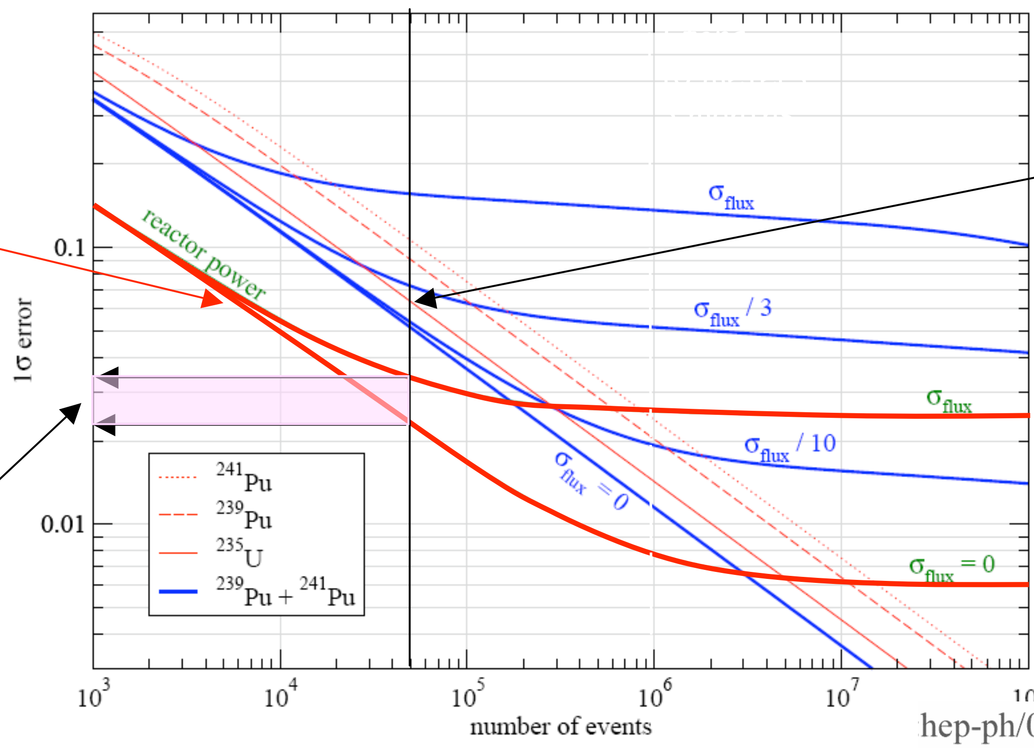
First Step: Thermal Power

- Thermal power is measured at ~2% (?) by the nuclear power companies
- Current measurement at reactor → 3% but possibility of improvement

- What can *only* neutrino do:
  - *Independent method looking directly at the nuclear core, from outside*
  - *Cross calibration of different power plants from different sites*

1σ error on thermal power measurement

2-3% measurement over a few days

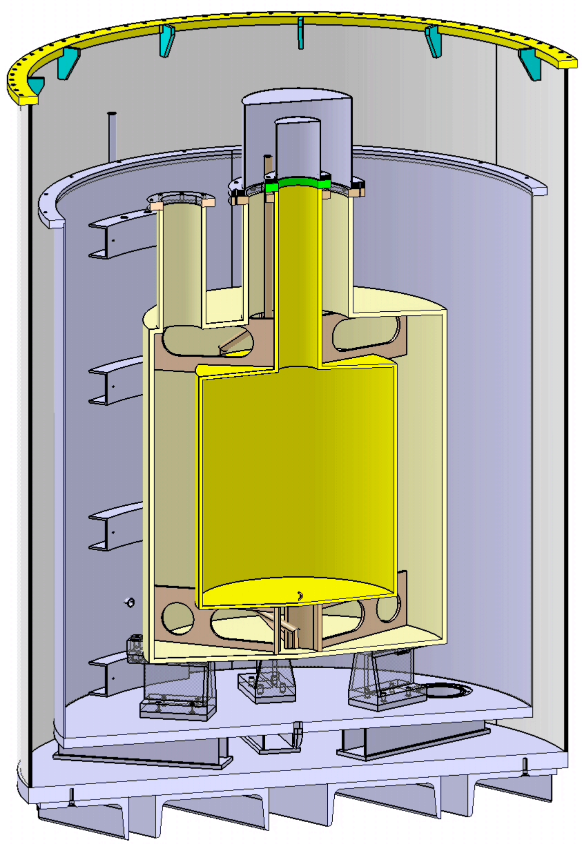


50 000 events within A few days

hep-ph/0407026 v2

Goal of the Double Chooz mockup

Last stage for the validation of the technical choices for the vessels construction and the integration of the detector at the Chooz site



APC, Univ. Munchen, MPIK Heidelberg, Saclay, Univ. Tuebingen

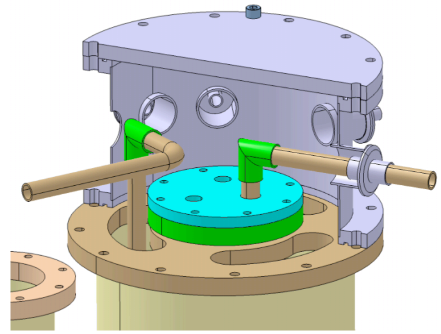
- ***Inner Target:***
  - *8 mm Acrylic vessel*
  - *Responsibility: Saclay*
  - *Composition : 80% dodecane, 20% PXE, 6 g/l PPO, 25 mg/l bis-MSB 0,1 g/l Gd (Carboxylate version Gd-CBX without the ROH stabilizers)*
  - *Volume: 115 l*
- ***Gamma Catcher:***
  - *12 mm Acrylic vessel*
  - *Responsibility: Saclay*
  - *Composition : 60% dodecane, 30% mineral oil 10% PXE (3 g/l PPO, 16 mg/l bis-MSB)*
  - *Volume: 220 l*
- ***Buffer region:***
  - *4 mm stainless steel vessel*
  - *Responsibility: Saclay*
  - *Mineral oil, 690 l*
- ***Veto:***
  - *1 cm Steel vessel (white paint → reflective)*
  - *Mineral oil, 500 l*

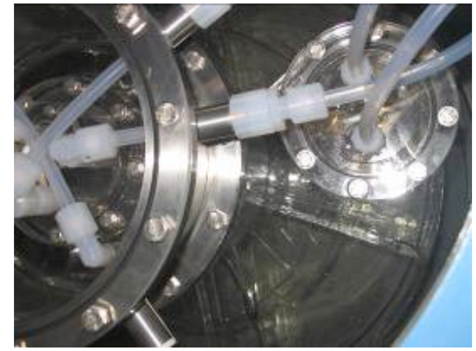
→ Overall liquid volume ~ 2 m³


dapnia
cea
saclay

Cleaning & Integration

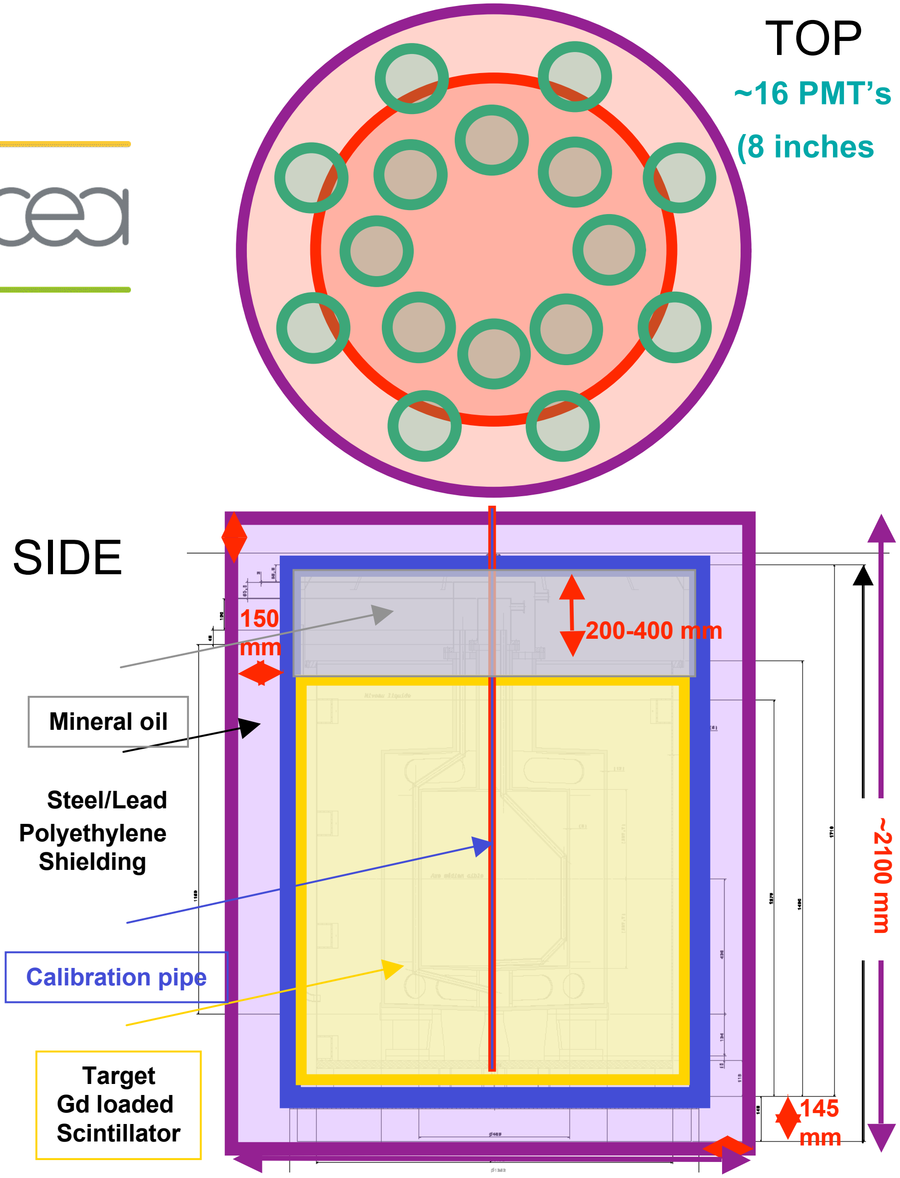
Filling system & Operations





- *All Teflon filling system for Double Chooz Target mock-up*
- *Monthly operation of the filling system to sample the Gd liquid scintillator*
- *Installed during the summer 2005 - dismantled during the summer 2006*

Concept of the instrumented mock-up



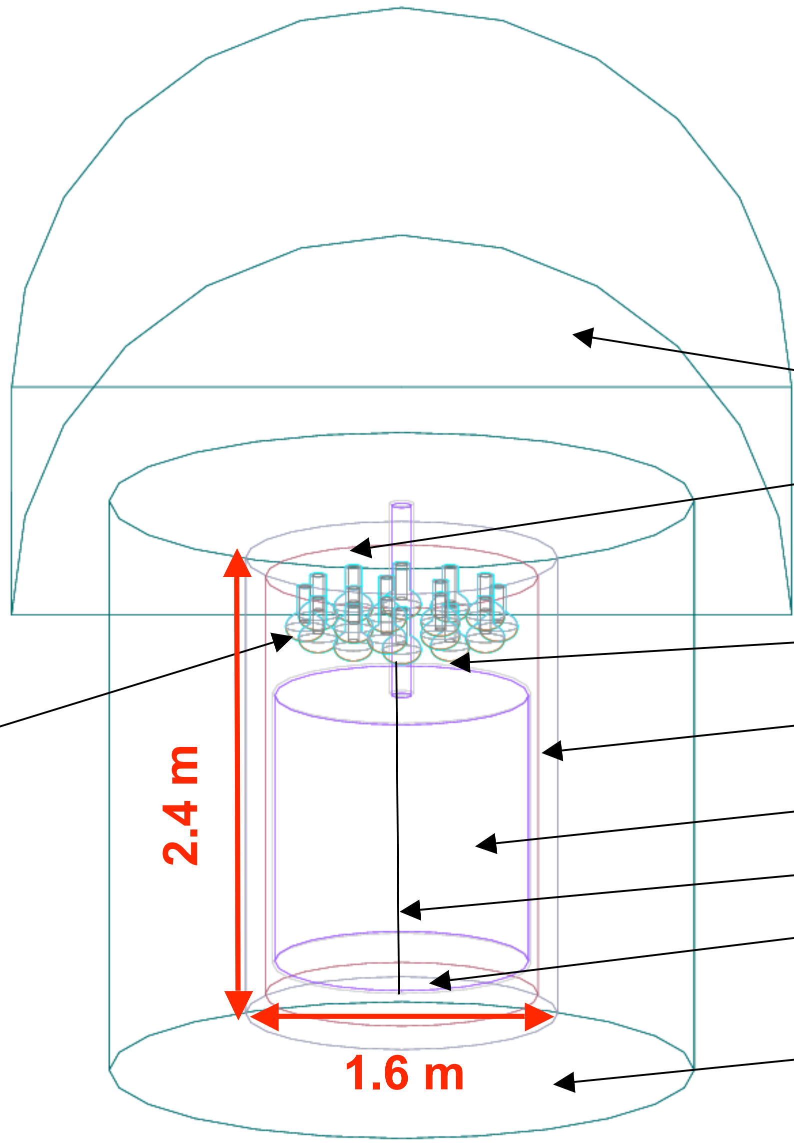
- ***AIEA/Industry requests:***
  - *Simple neutrino detector*
  - *Small (< 4 m x 4 m x 4 m in any case ?)*
  - *Safe*

- ***Approach: is a SIMPLE instrumented mock-up like design be suitable for***
  - ***Thermal power measurement***
  - ***AIEA Safeguarg issues ? (spectrum measurement)***

- ***Instrumented mockup-like design : NuTherm Concept***
  - *Target mass between 1 and 2 tons*
  - *Monolithic cylindrical detector*
    - *Simple mechanics*
    - *Easily movable*
  - *<16 PMTs on Top*
    - *Detector response ?*
    - *reduce leaks hazards*

GEANT4 Detector Geometry

GEANT4 Simulation based on the GLG4Sim & DCGLG4Sim packages



Detector Hall

Chimney : 12 mm Acrylics vessel
Chimney scint. volume (8 liters)

Buffer liquid (1.5 m^3 min. oil, L~50m)

Steel/Lead Shielding (100 mm)

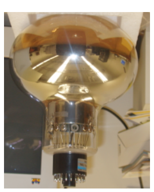
Buffer Vessel (Stainless steel + surface)

Target Volume (1.86 m^3 Gd_scint, L~5m)

Target Vessel: 12 mm Acrylics vessel

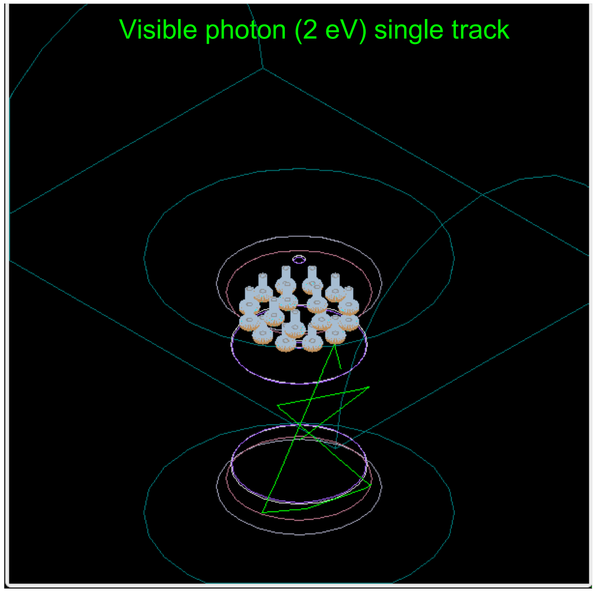
Detector Pit (arbitrary dimensions)

17 PMTs (8'')



Geant4 Simulation: Optical Model

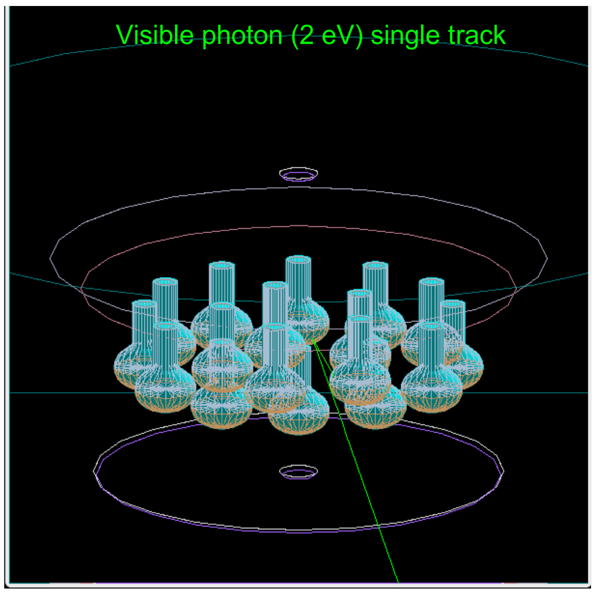
Full detector from above

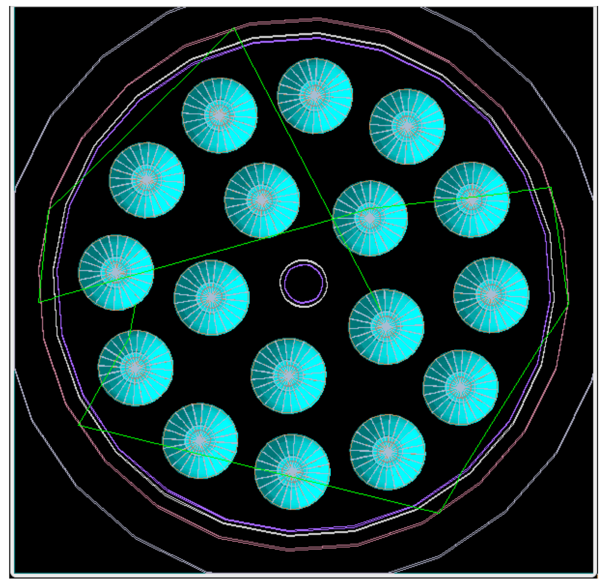


- **Target liquid**
  - 20% PXE+80%dodecane
  - 0.1% Gd-doped Scintillator
  - Fluors: 6 g/l PPO, 25 mg/l Bis-MSB
  - d=0.8, 7000 photos/MeV, L~5 m
- **PMTs**
  - 2 rings of 12 and 5 8'' modules
  - Full PMT optical Model implemented
  $R(\theta,\lambda)$, $A(\theta,\lambda)$, $T(\theta,\lambda)$

- **Acrylics: 12 mm (L~5 m, cutoff <400 nm)**
- **Buffer Surface:** ***Stainless steel* OR *Tyveck***

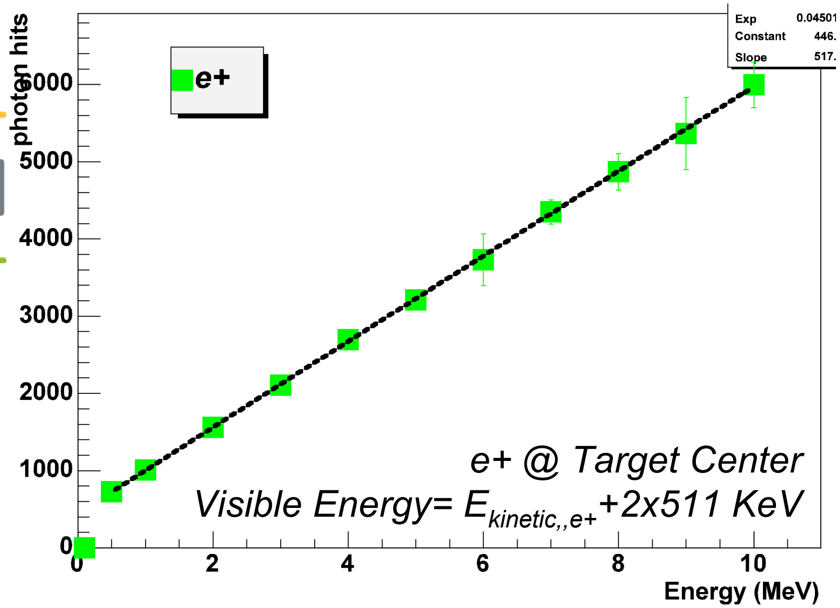
17 PMTs, side view





17 PMTs, Top view

Light Outut & Time Response



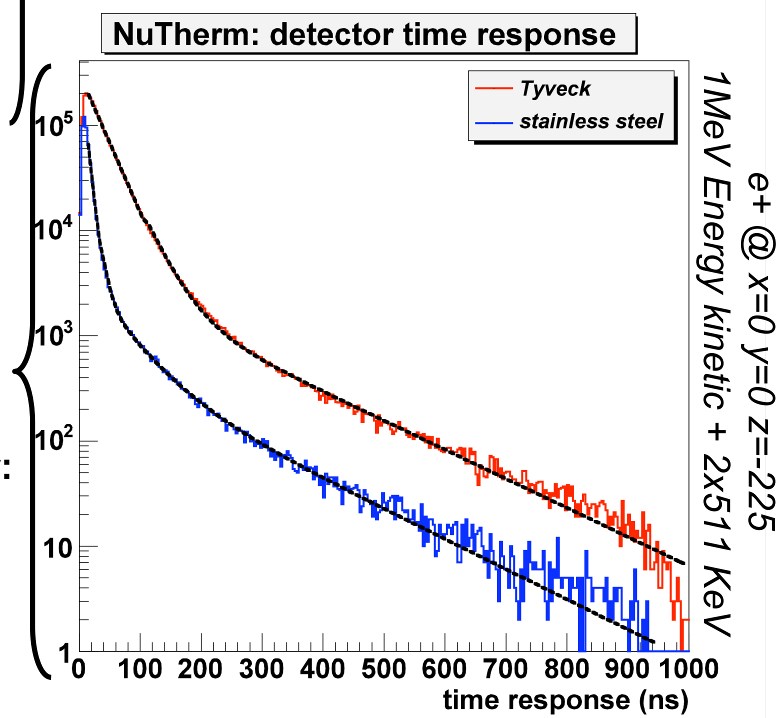
Good light output with 17 PMTs

***Option 1:* Buffer vessel coated with stainless steel : Glisur model (polish=0.1 & Reflectivity = 40%) → 150 p.e. / MeV**

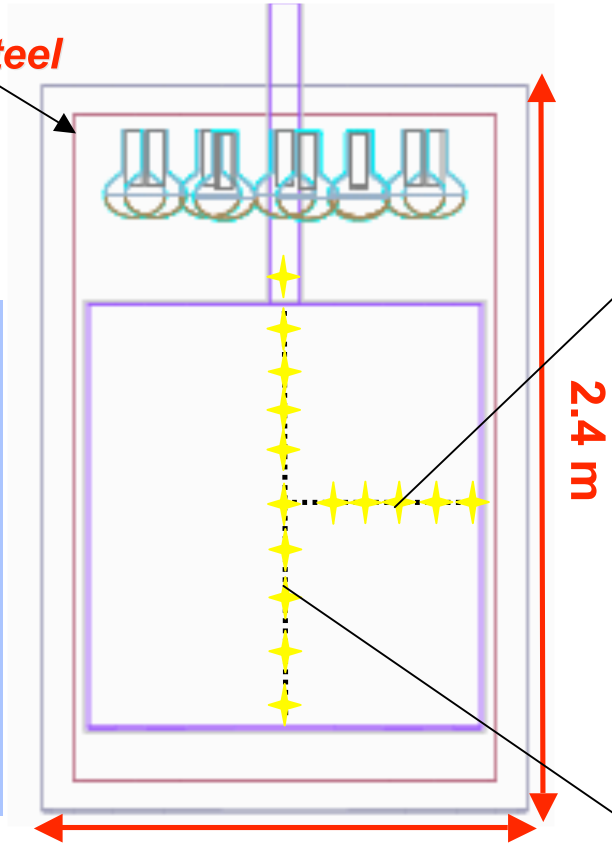
***Option 2:* Buffer vessel coated with Tyveck reflector: Glisur model (polish=0.1 & Reflectivity = 90%) → 800 p.e. / MeV**

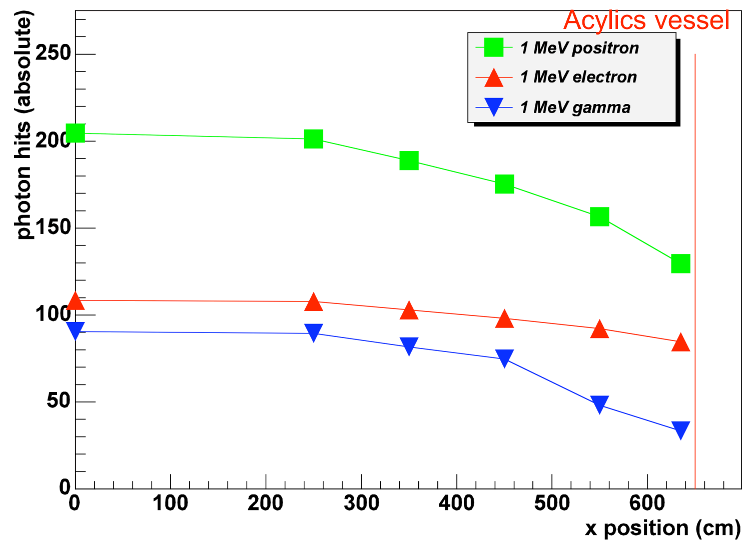
***Option 1:* Buffer vessel coated with stainless steel:**
- **Light collection = sum of two exponentials:**
  τ_1~10 ns τ_2~ 50 ns
  99% of the signal within 250 ns

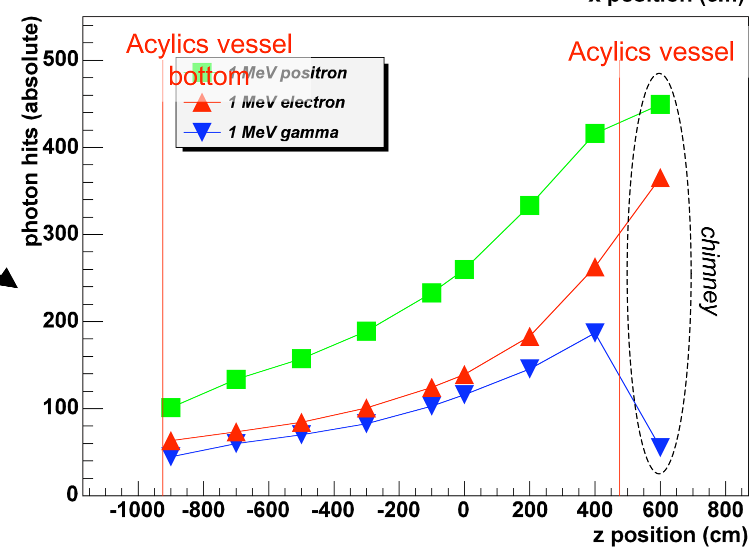
***Option 2:* Buffer vessel coated with Tyveck reflector:**
- **Light collection = sum of two exponentials:**
  τ_1~30 ns τ_2~ 150 ns
  99% of the signal within 300 ns



Opt1: Spatial Response: e^+, e^-, γ



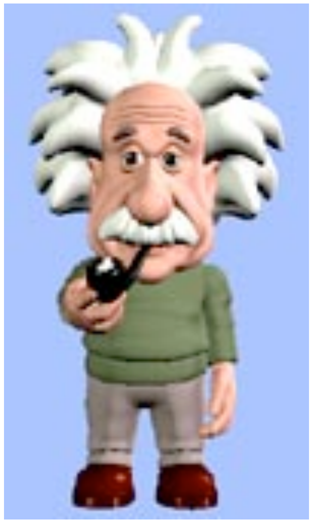


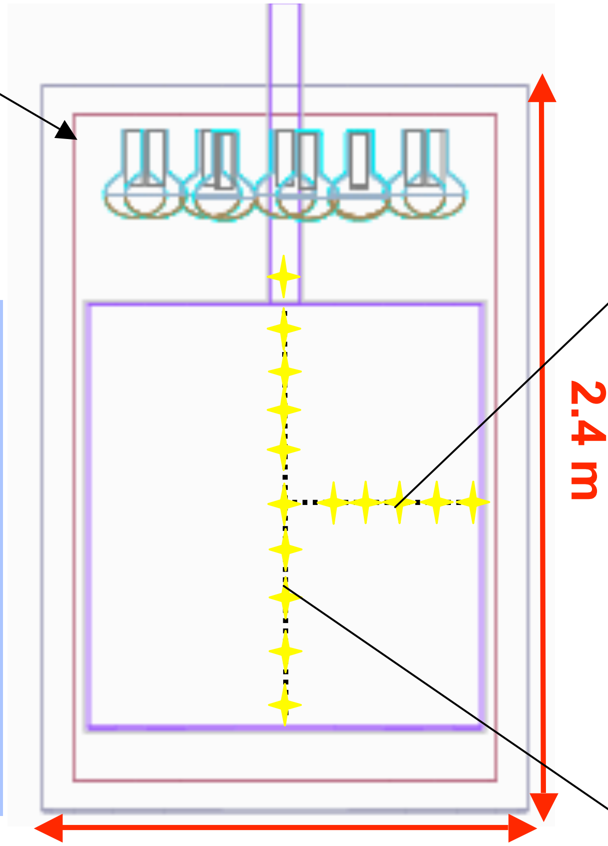


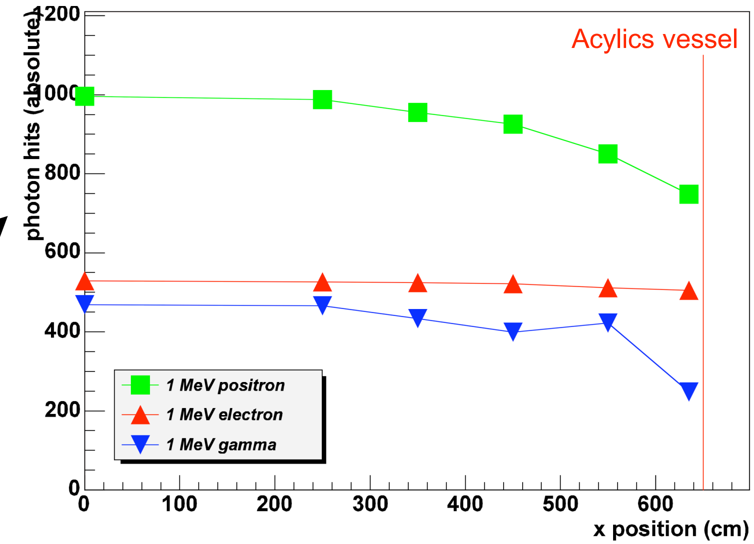
- **X scan:**
  - e^+: 100% from center to the edge !!!
- **Z scan:**
  - e^+: light collection effect + escape → >400% variation

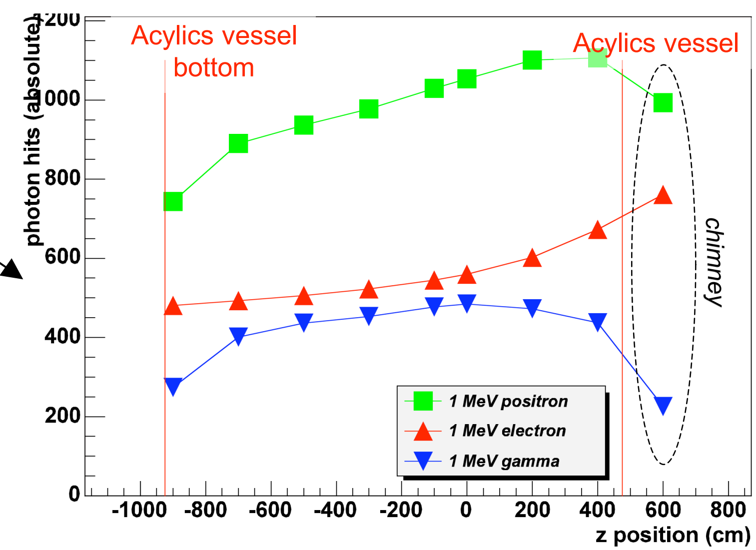
→Difficulty to reconstruct the ν energy
(no vertex reconstruction)

Opt2: Spatial Response: e^+, e^-, γ









- **X scan:**
  - e^-: a few % variation from the center to the edge
    - *→ very good light collection due to Tyveck*
  - e^+: 20% from center to the edge → 511 KeV γ escape

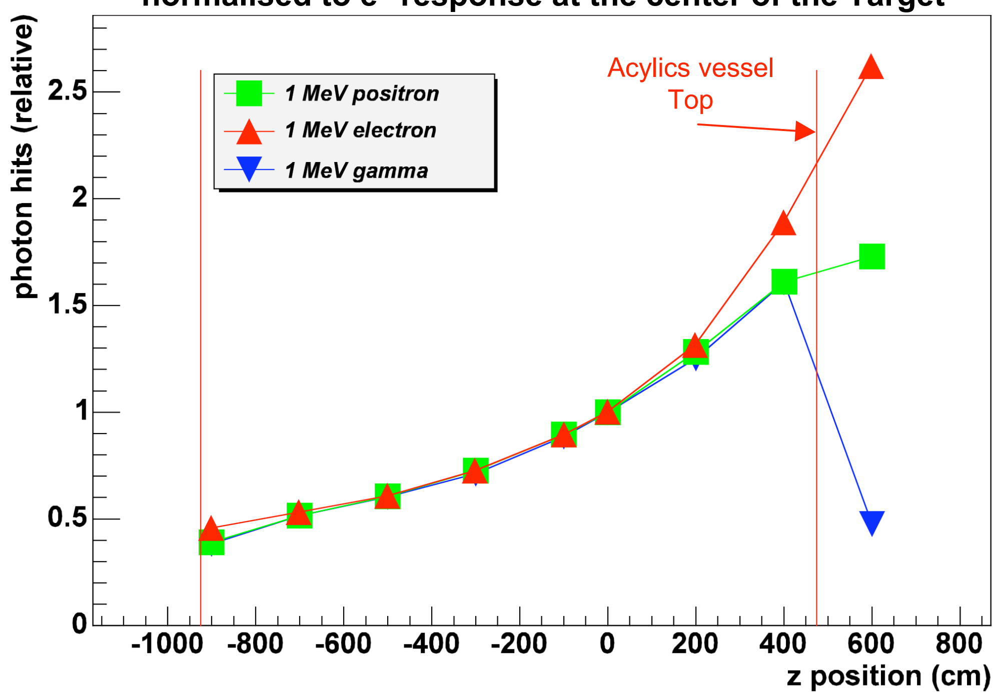
- **Z scan:**
  - e^+: light collection effect + escape → 35% variation

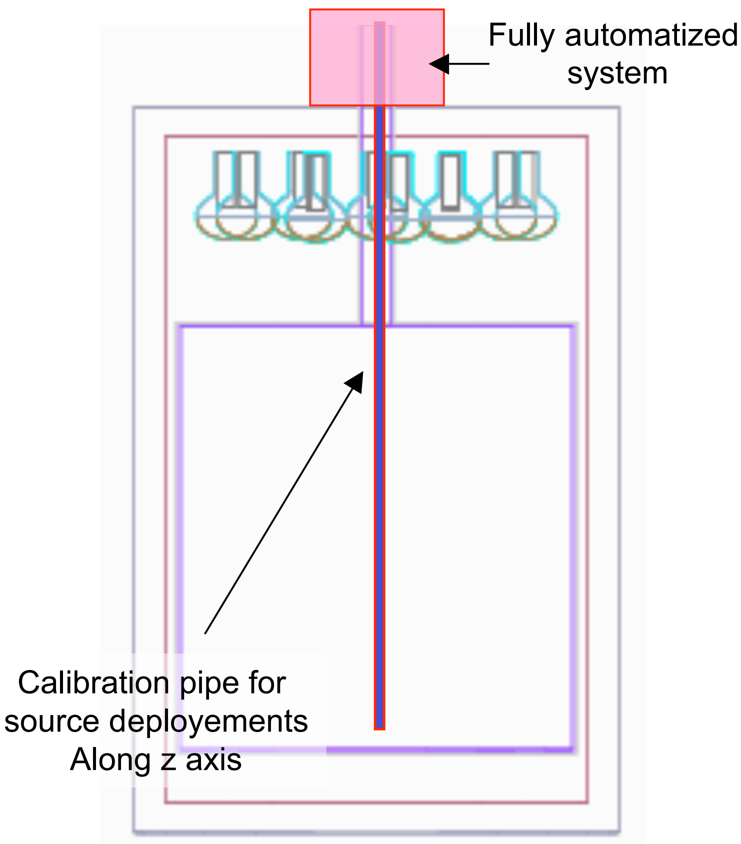
Calibration

- **Goal: monitor detector response along z axis**
  - Case 1: no spatial reconstruction → Only a relative calibration over the detector live time
  - Case 2 : use some time information to do “some” reconstruction + correction

- **Gamma radioactive sources**
  - Allow to follow the positron response variation with z
  - Automatization of the calibration

Relative detector response along the z axis normalised to e^+ response at the center of the Target





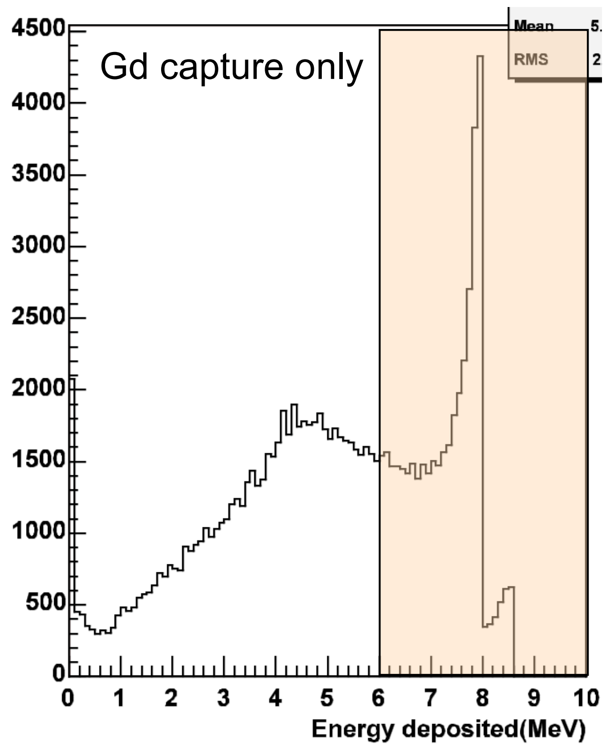
Spatial Response: 20 keV neutrons

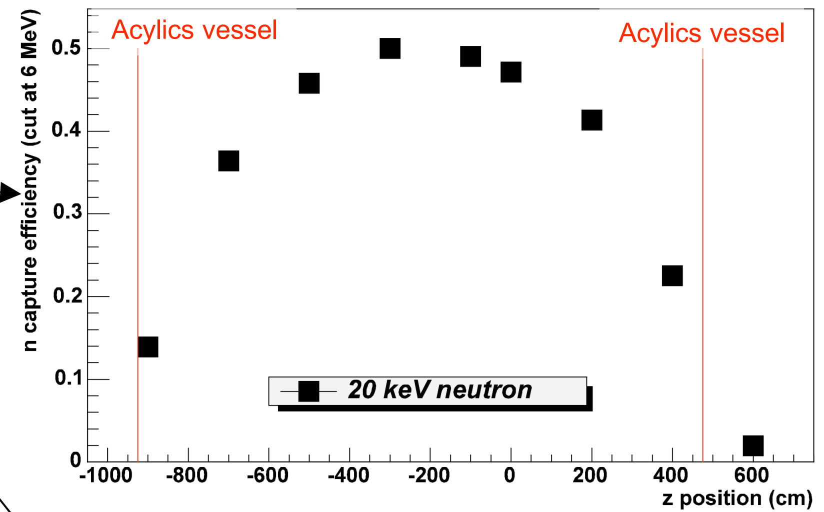
- *20 keV neutrons – Z Scan*
- *Thermalization + Gd-capture*

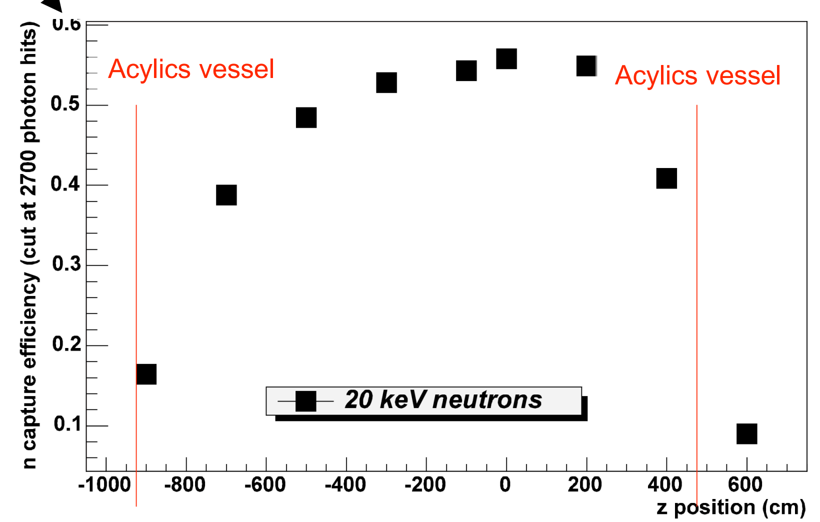
- *Efficiency defined as E>6 MeV vs Z*
  (energy deposited)

- *Efficiency defined as E>2700 p.e. vs Z*
  (energy deposited + light collection)

- 20 keV n uniformly distibuted in the Target
- 6 MeV cut , 20 KeV → Eff. = 25.6 %





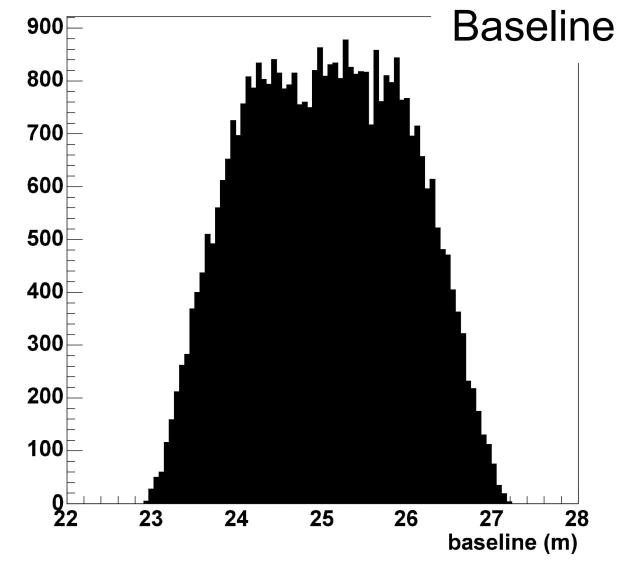


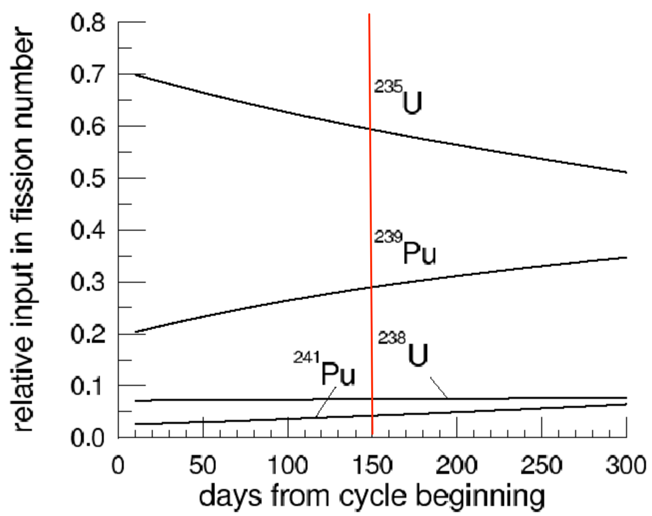
Application to Reactor Neutrinos

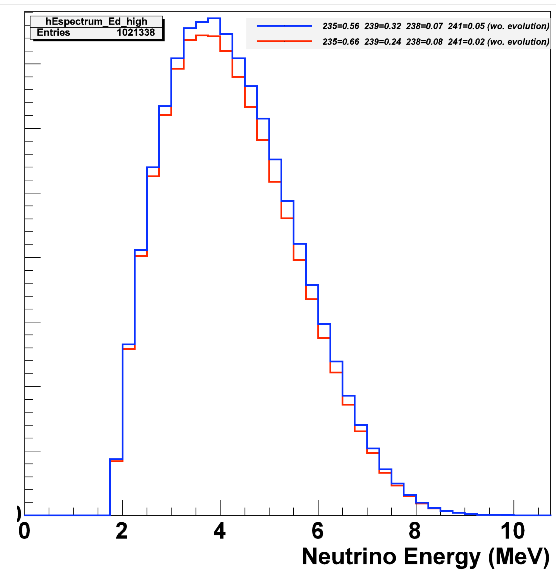
- ***Nuclear reactor***
  - *Single EDF-N4 unit of 4.25 GW (thermal)*
  - *Extended core 3 m x 3 m x 4 m*
  - *averaged fuel composition*
    - *Typically (in fraction of fissions)*

      $^{235}U = 0.56$ $^{239}Pu = 0.24$

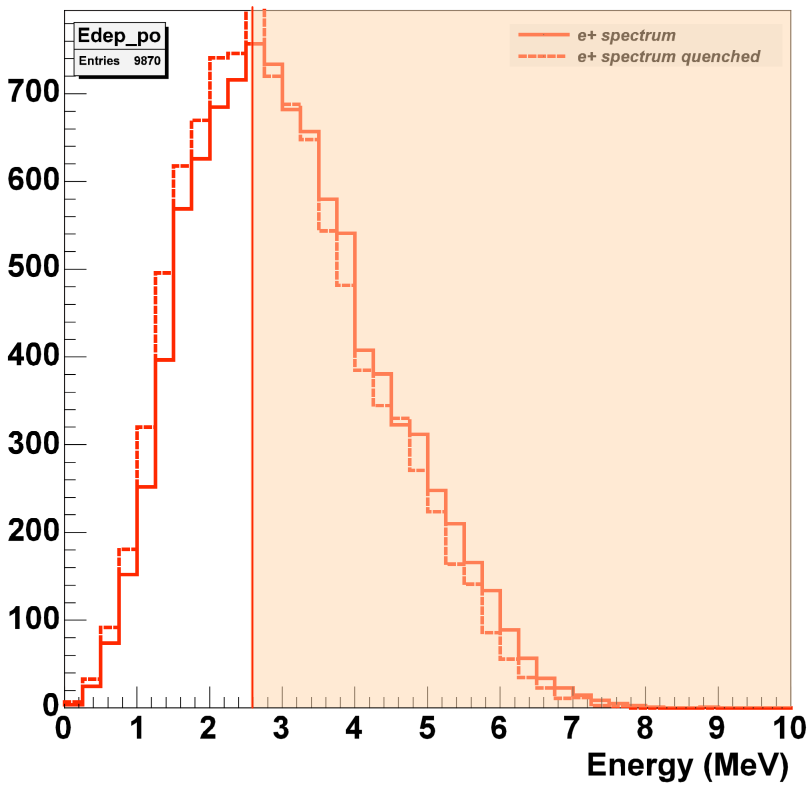
      $^{238}U = 0.08$ $^{241}Pu = 0.02$
- ***NuTherm detector***
  - *@25 meter (1 meter RMS)*
  - *Target cylinder R=0.65 m, H=1.4 m*
  - *no spill in/out accounted for*
  - *1.5 tons of Double Chooz Target Scintillator*
  - *10000 events/d (no efficiency)*

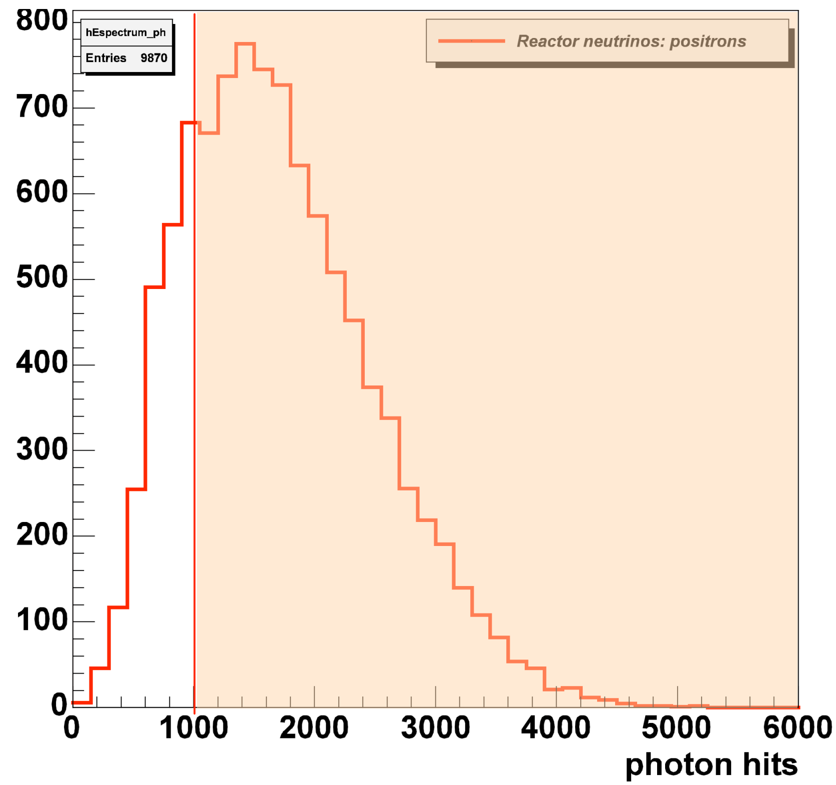






Neutrino Induced Positron

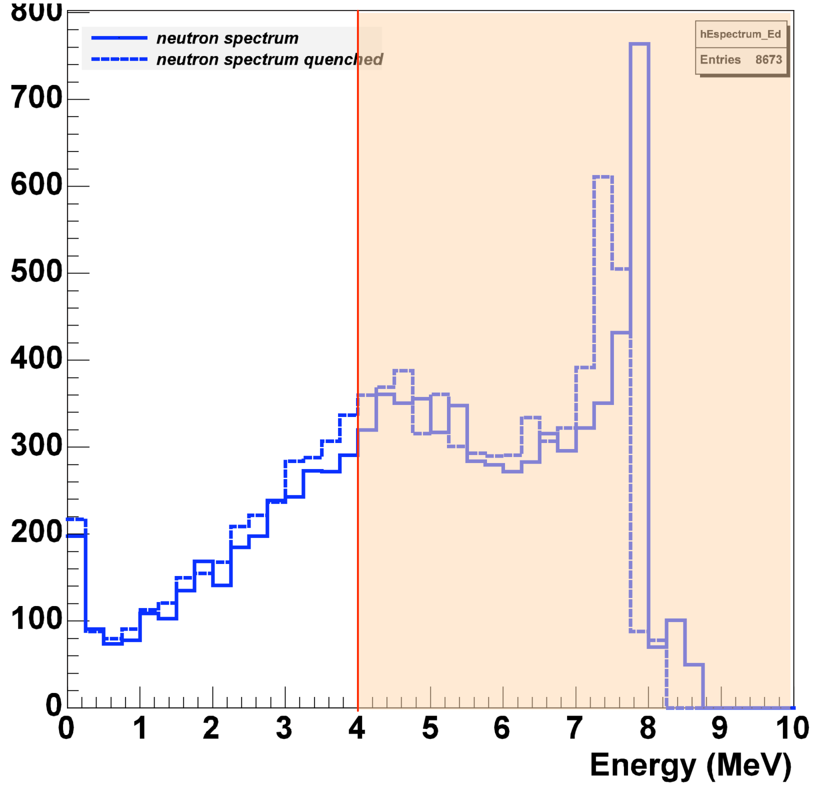


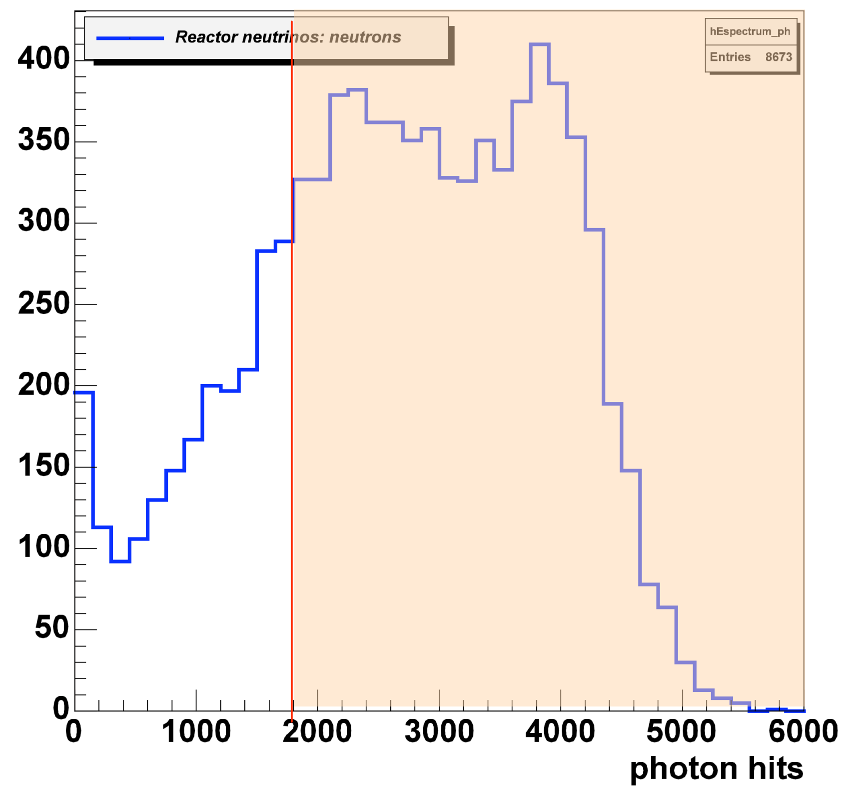


- ***Energy deposited***
  - ***Low E tail due to 511 keV γ escape***
  - ***Quenching from Birk's law***
    d(E quenched) = dE / (1 + kB dE/dx)
  - ***Efficiencies***
    - *1 MeV → 98.2 %*
    - *2.5 MeV → 71.8 %*
    - *3 MeV → 50.4 %*

- ***Photoelectron spectrum***
  - ***Account for detector response***
  - ***looks like reactor induced e^+ !***

Neutrino Induced Neutrons



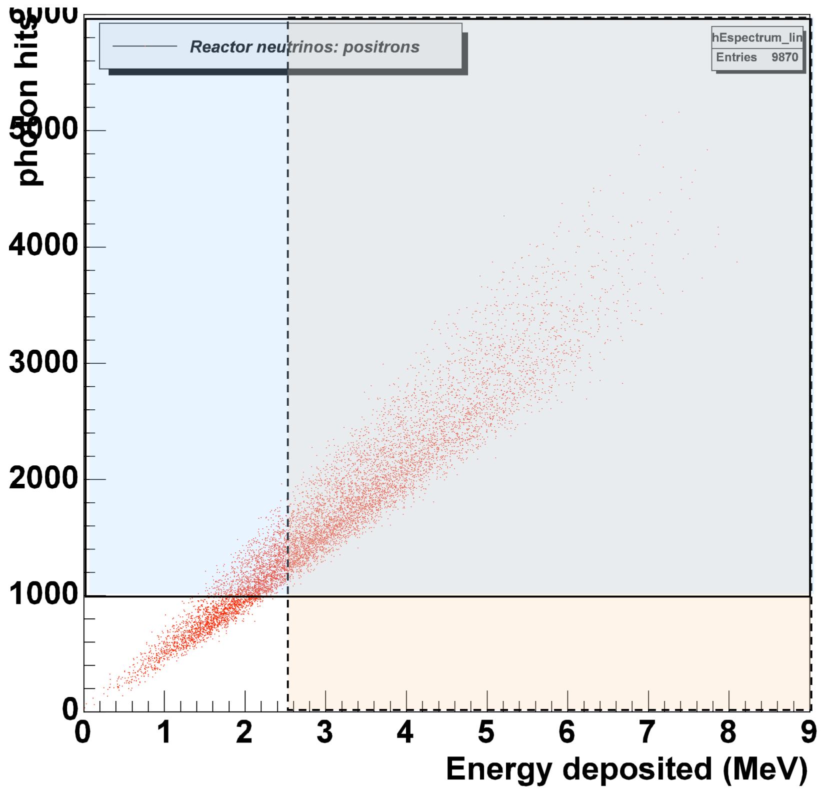


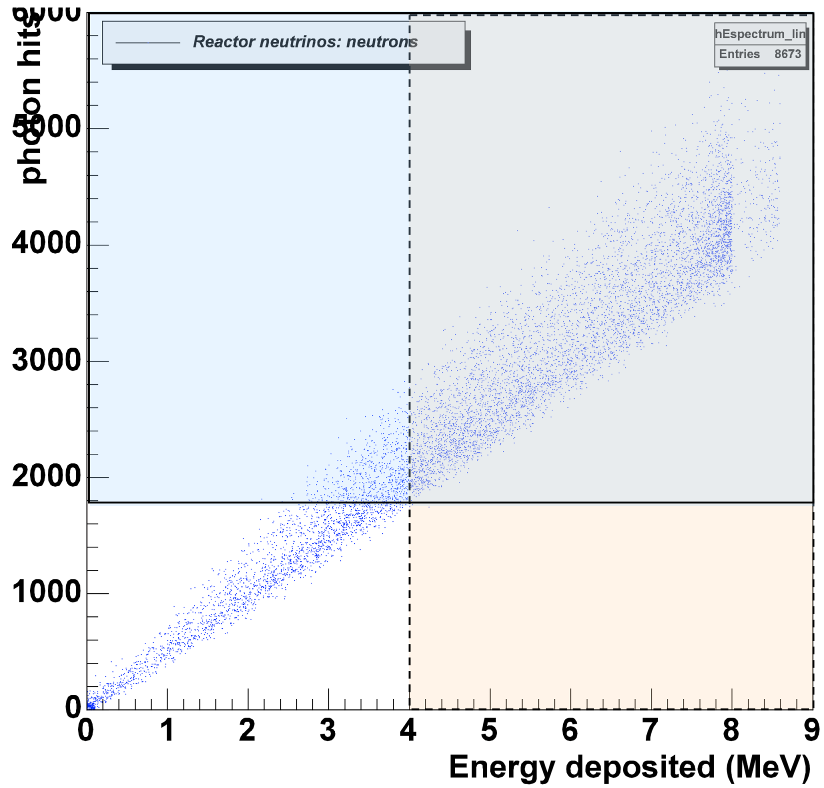
- ***Energy deposited***
  - ***8 MeV Gd peak (Only)***
  - ***Low E tail due to γ from n-capture on Gd***
  - ***Quenching from Birk's law***
  - ***Gd capture ε_{Gd} ~ 88%***
  - ***Efficiencies of Energy cut:***
    - *4 MeV → 68 % & 6 MeV → 25.6 %*

- ***Photoelectron spectrum***
  - ***Account for detector response***

  → Spread of the n-Gd capture peak

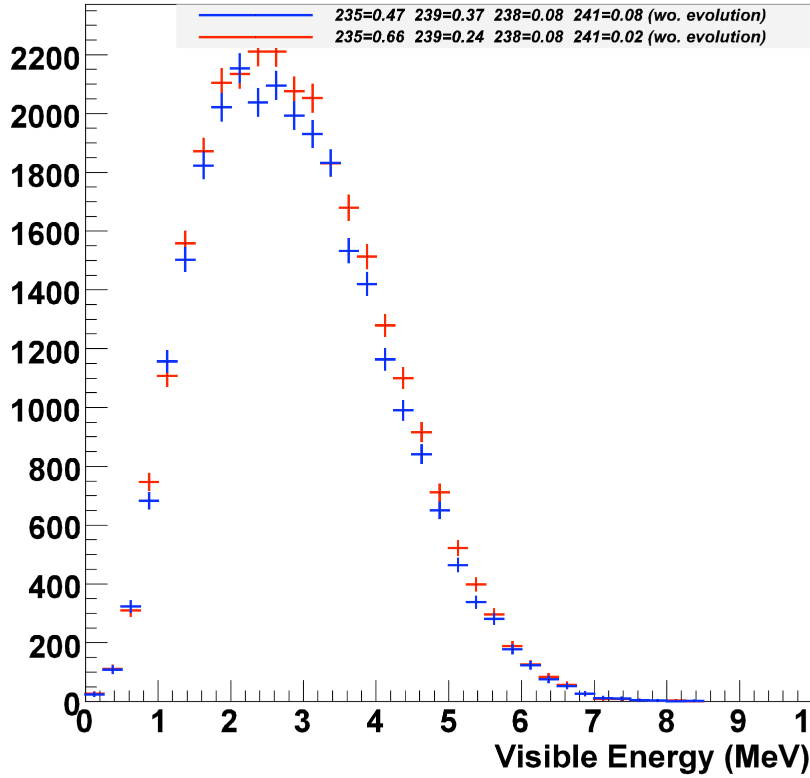
Detector Efficiency

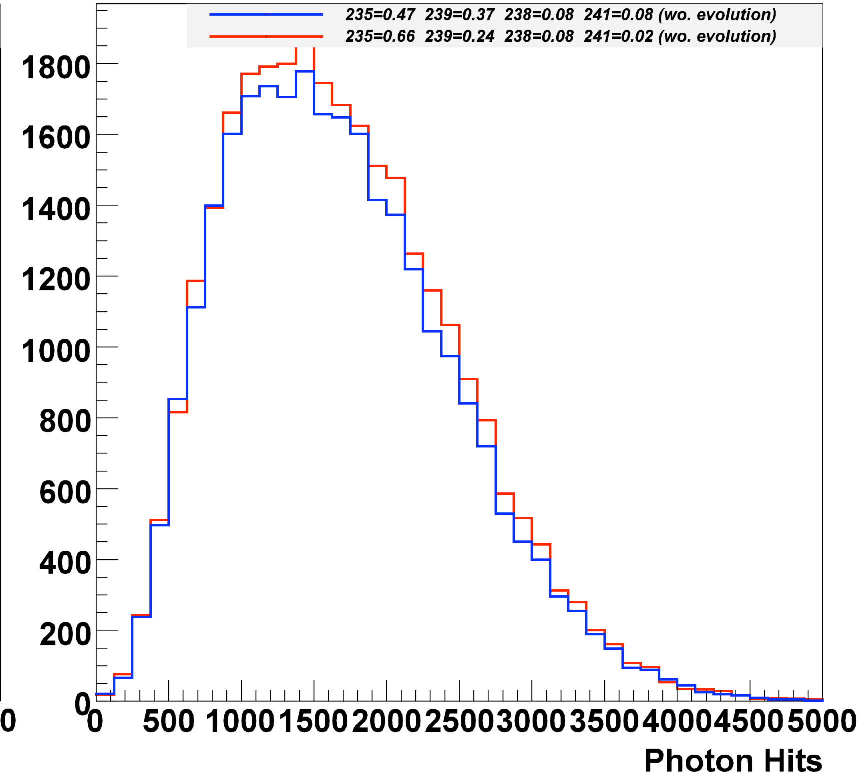




- ***No position reconstruction***
  because highly reflective Buffer surface
- ***Energy response***
  - ***E_{e+}> 2.5 MeV → p.e.> 1000 → ε_e~ 85 %***
  - ***E_n > 4 MeV → p.e. > 1800 → ε_n~ 79 %***
- ***Time cut***
  - *coincidence time of 100 μs*
  - *ε_t ~ 97%*
- ***Global efficiency***
  - ***ε_{tot} ~ ε_e x ε_{Gd} x ε_n x ε_t ~ 0.57***

Burn-up Follow Up (Preliminary)





- ***2 fixed fuel compositions (in fraction of fission per isotope)***

^{235}U=0.47	*^{239}Pu=0.37*	*^{238}U=0.08*	*^{241}Pu=0.08*	**27850±167 evts**
^{235}U=0.66	*^{239}Pu=0.24*	*^{238}U=0.08*	*^{241}Pu=0.02*	**29275±171 evts**

- ***Nul Hypothesis: the two 'burn-up' induce identical p.e. spectra***
  - ***Kolmogorov-Smirnov statistical test***
    - *~28500 events → ~5 days of data taking (including efficiencies)*
    - ***Quenched Energy spectrum → KS prob. 0.04 (shape only) & $<10^{-8}$ (rate+shape)***
    - ***Photoelectron Hits spectrum → KS prob. 0.05 (shape ony) & $<10^{-8}$ (rate+shape)***

Systematics & Backgrounds

- ***Thermal power measurement will rely on the absolute normalization***
  (but relative measurement of interest for burn-up, cross calibration)
- ***Non proliferation applications will rely on relative measurements***
  (try to detect an 'abnormal' burn-up)

- ***Systematics***
  - ***Reactor flux & spectrum known at the 2% level***
  - ***Detector systematics***
    - ***1.5% achievable?***
    - ***dominated by spill in/out & prompt/delayed energy cuts***

- ***Backgrounds* (correlated will dominate as usual …)**
  - **Cosmic muons create fast neutrons through spallation and muon capture in the rock surrounding the detector**
  - **Fast neutron slows down by scattering into the scintillator; it can deposit between 1-8 MeV and be later captured on Gd !**
  → Major difficulty !!!

- ***Shielding***
  - ***Cosmic muon: Overburden equivalent to a mass of 20 meter of water or more***
    Plastic scintillator on the Top/sides to Veto the cosmic muons
  - ***External gamma's from U/Th: ~5-10 cm of lead***
  - ***External neutron: ~5-10 cm of neutron absorber (polyethylene, etc …e***

→ But background study is site dependent …

Conclusion & Outlook

- ***Neutrinos could 'image' the nuclear power station nuclear cores***
  → *Thermal power measurement & non proliferation applications*

- ***Neutrino physics & technlogy is known but detectors needs to meet the applied physics goals:*** ***safe, robust, and remotely operable, maybe movable?***

- ***Detector design sutdied:*** *a simple monolitic detector with PMTs reading on the Top*
  - *3 m x 2 m*
  - *~16 PMTs + reflective coating*
  - *Target: 1.8 m^3*
  - →*Measurement of the reactor neutrino energy spectrum*
  - →***Capability to disentangle betwezn 2 'burnup' within a few days***
  - →***Prospect: Need to be confronted to realistic diversion scenario***

- ***Shielding/Veto to be design according to the experimental site + baseline***

- ***Prospect***
  → ***Other detector designs + site study***
  → ***Funding request in France for prototype construction …***